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Danish Chinese Center for Nanometals - Annual report 2010

Winther, Grethe

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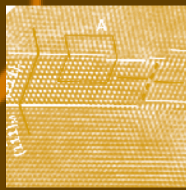

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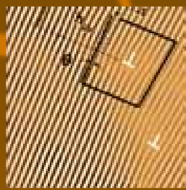
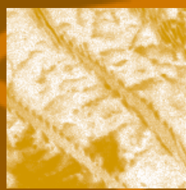
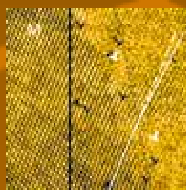
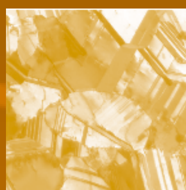






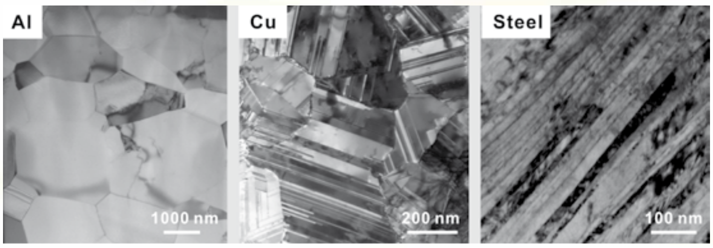


Danish – Chinese Center for Nanometals

Nanometals

The Center investigates metals, including alloys, with internal length scales ranging from a few nanometers to a few micrometers. These are termed nanometals, and have new and interesting properties, such as exceptional mechanical strength, which are related to their internal structure. The scientific focus is to understand and control the mechanisms and parameters determining the mechanical and physical properties of such nanometals as well as their thermal stability.

The internal structure of nanometals is highly diverse, consisting of different types of internal interfaces, spatially arranged in different morphologies, as exemplified by equiaxed grains in aluminum, lamellar nanotwins within equiaxed sub-micrometer grains in copper, and lamellar boundaries between two phases in steel. The morphology as well as the chemical composition of nanometals can be manipulated and are key features to be optimized for future applications of nanometals.



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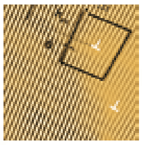
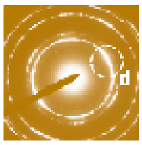
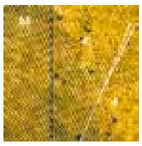
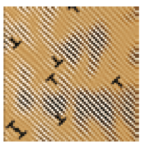








Danish – Chinese Center for Nanometals

Introduction

The midterm of the three-year period of the Center for Nanometals is approaching fast and we are glad to present this report for 2010 showing that we have been successful in establishing a close and productive collaboration between Chinese and Danish scientists both at the senior and junior levels. The results of this collaboration illustrate both synergy and complementarity in the research and also the possibility of future innovative applications.

Exchange is a keyword when the center is carrying out its research projects and the center format has created an excellent frame. Young Chinese scientists have been at Risø DTU for longer periods and senior scientists from China and Denmark have been on reciprocal visits which have been long enough to maintain momentum in the joint projects and to create new ones. An important factor in making such exchange visits efficient and successful has been the personal connections between senior and junior researchers as three Chinese post docs and one PhD student at Risø DTU have previously been supervised by professors participating actively in the center from IMR SYNL, Tsinghua University and Chongqing University.

The bridging between science and scientists in China and Denmark has also been demonstrated clearly through an international workshop on mechanical behavior of metallic materials Oct. 10-14, 2010, in Jiuzhaigou, China, sponsored by the National Natural Science Foundation of China, Institute of Metal Research, CAS and Risø DTU. The workshop had as its objective to bring together senior scientists and researchers from around the world to review recent scientific achievements in materials science covering synthesis, characterization, modeling and performance. Presentations were given by 22 speakers of which 14 were from the four center partners and the rest from high level universities in China, Europe and USA. The format of the meeting was highly successful as many key problems could be discussed among peers. It demonstrated clear synergies between activities within the center but also an outreach to other scientists within the materials field.

Synergy and complementarity are keywords when planning and performing research within the center and the 30 joint projects and 37 publications demonstrate that the center is successful. This is also the case when it comes to related research activities not being part of the center programs. Examples are (i) that properties of metals deformed at high strain rate at IMR SYNL guide research at Risø DTU on advanced materials for transport, (ii) that the strong steel wires delivered by Chongqing University is evaluated at Risø DTU for application in blades for wind turbine generators and (iii) that research within the center starts to require 3DXRD experiments based on techniques developed within the center 'Metal Structures in Four Dimensions' hosted by Risø DTU and also supported by DNRF.

For an active research collaboration it must be expected that projects are revised as results are appearing but significant revisions of the research program have not been necessary. On the contrary the activities have been expanded to cover research in the field of materials to be used in a fusion reactor, especially within the ITER program in which both China and Denmark participate. The research has been started at Tsinghua University and it is sponsored by the Institute of Plasma Physics, Chinese Academy of Sciences, Hefei. The first project where Risø DTU will participate covers thermo-mechanical processing of tungsten which has high strength at high temperatures and where it is expected that a deformed nanostructure will increase the resistance towards radiation damage. Joint research will be carried out at Tsinghua University and Risø DTU in collaboration with the Institute of Plasma Physics (Professor Dr. Guang-Nan Luo) which will also be responsible for testing under irradiation. This new project will also be in support of a Risø DTU program on tungsten under the auspices of the Fusion Energy Materials Science – Coordination Action (FEMaS - CA).

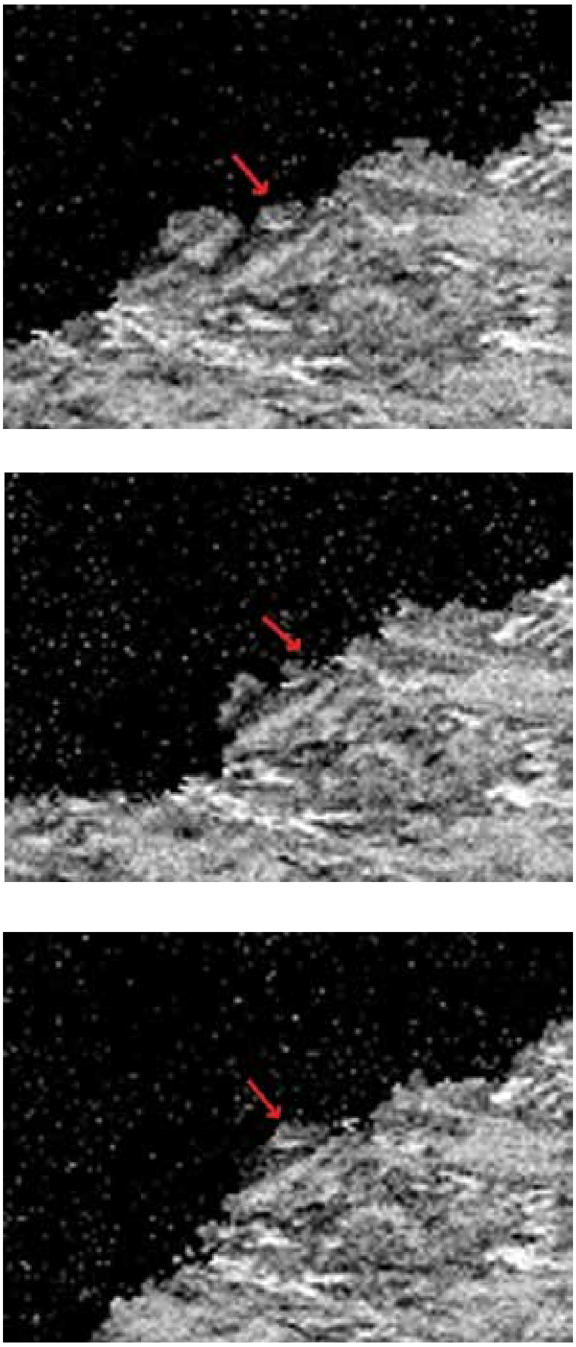
In conclusion, 2010 has established a good basis for fulfillment of the vision of the center, namely to create a strong long-term collaboration between Chinese and Danish Scientists focusing on fundamental research in the field of nanoscience and nanotechnology with an emphasis on nanometals. We are therefore looking forward to the coming years – from novel ideas to fascinating results based on the excellent collaborative spirit which has flourished in the center in 2010.

国际金属材料力学行为研讨会2010年10月10-14日， 中国九寨沟

Group picture taken at the International Workshop of the Mechanical Behavior of Metallic Materials in Jiuzhaigou, China.

Local boundary migration

With the aim of identifying mechanisms and key parameters which guide the development of nanostructures with improved thermal stability, grain boundary migration during recrystallization is characterized in a close collaboration between Risø DTU and Tsinghua University. The local boundary migration has been followed by electron channeling contrast microscopy in cold-rolled pure aluminium. Many local protrusions/retrusions on the migrating boundary develop by faster/slower movement of small boundary segments for short periods of time. Contradictory to common assumptions, it is observed that protrusions/retrusions can provide a local driving force which is comparable in magnitude to the driving force from the stored energy in the deformed matrix. The formation and evolution of protrusions/retrusions can be directly related to the deformed microstructure and they contribute to the stop-go motion of typical recrystallization boundaries.

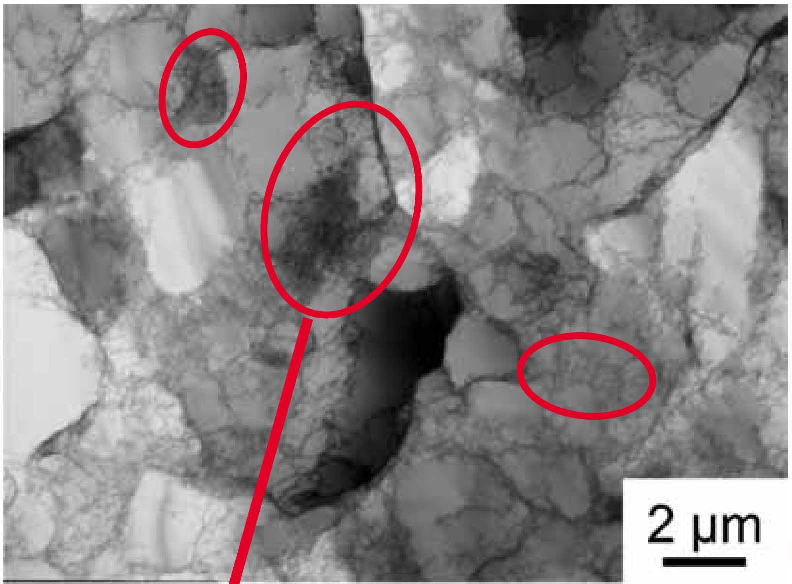


Snapshots at different times of a migrating boundary during annealing of cold-rolled pure aluminium showing protrusions and retrusions. The protrusion marked by the arrow in the top snapshot develops into a retrusion in the bottom shapshot taken about 5 minutes later.

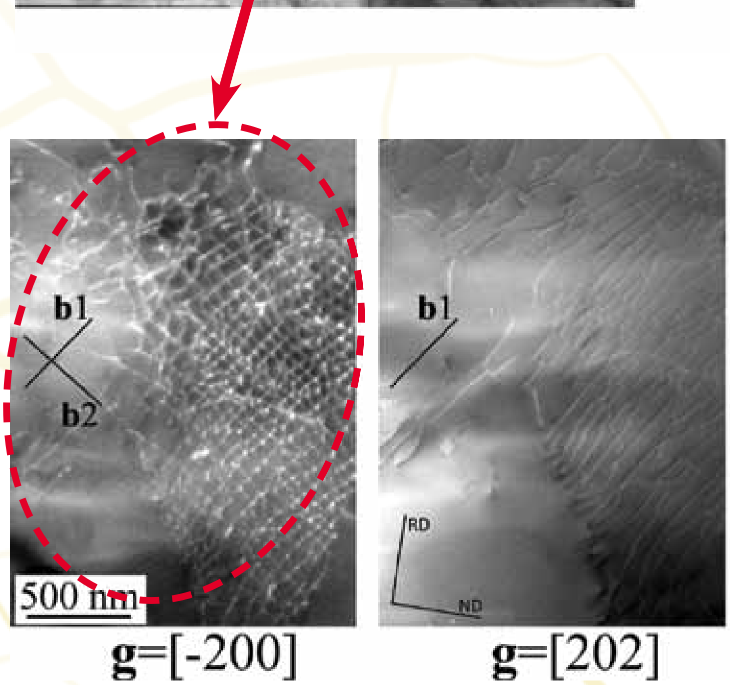
Dislocations, slip systems and boundaries

In order to understand the mechanisms behind the deformation-induced formation of dislocation boundaries an extensive study of the dislocation content within such boundaries has been conducted in collaboration between Risø DTU and Tsinghua and Chongqing Universities, involving exchange of a PhD student. All boundaries are from the characteristic equiaxed cell structure in grains of near-Cube orientation in high purity cold-rolled aluminium. To provide a good basis for comparison, ten boundaries almost perpendicular to the transverse sample direction were studied using transmission electron microscopy. The ten boundaries all consist of a regular square grid of screw dislocations with Burgers vectors corresponding to the expected active slip systems, revealing a systematic boundary formation process and demonstrating the strong link between the identity of the slip systems and the characteristics of the boundaries in a grain.

Transmission electron micrograph of dislocation boundaries forming a cell structure. Red circles mark boundaries lying in the plane of the foil .



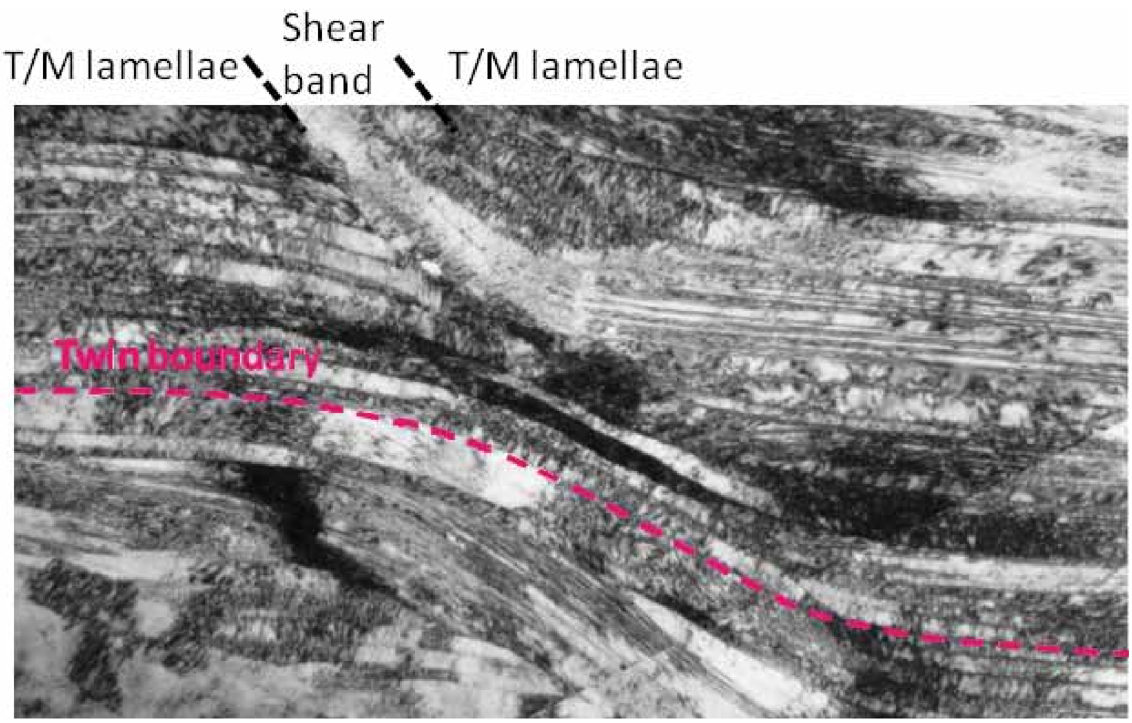
Two high magnification images of the same boundary using different diffraction vectors, g. Two sets of dislocations (b1 and b2) are visible in the left image and only one in the right. By means of different diffraction vectors, the Burgers vectors of the dislocations are determined as coming from the active slip systems.



Development of shear bands

Shear banding is an important mode of inhomogeneous deformation. Shear bands may account for a large volume fraction of the sample and have significant effects on the evolution of texture and microstructure. The development of a shear band in a nanoscale twin/matrix (T/M) lamellar structure produced by dynamic plastic deformation has been investigated jointly by IMR SYNL and Risø DTU, including exchange of a PhD student. By means of transmission electron microscopy and high resolution electron microscopy, nucleation of shear bands was found to occur within a 100-200 nanometer wide region. The nucleation mechanism consists of three steps, namely i) initiation of localized deformation associated with detwinning, ii) evolution of a dislocation structure within the detwinned band and iii) transformation of the detwinned dislocation structure into a subgrain structure of nanometer dimensions. After completion of the nucleation process, the shear band thickens by migration in opposite directions of the two interfaces between the shear band and the adjoining twin/matrix lamellae.

Sample deformed by dynamic plastic deformation showing pronounced shear bands.

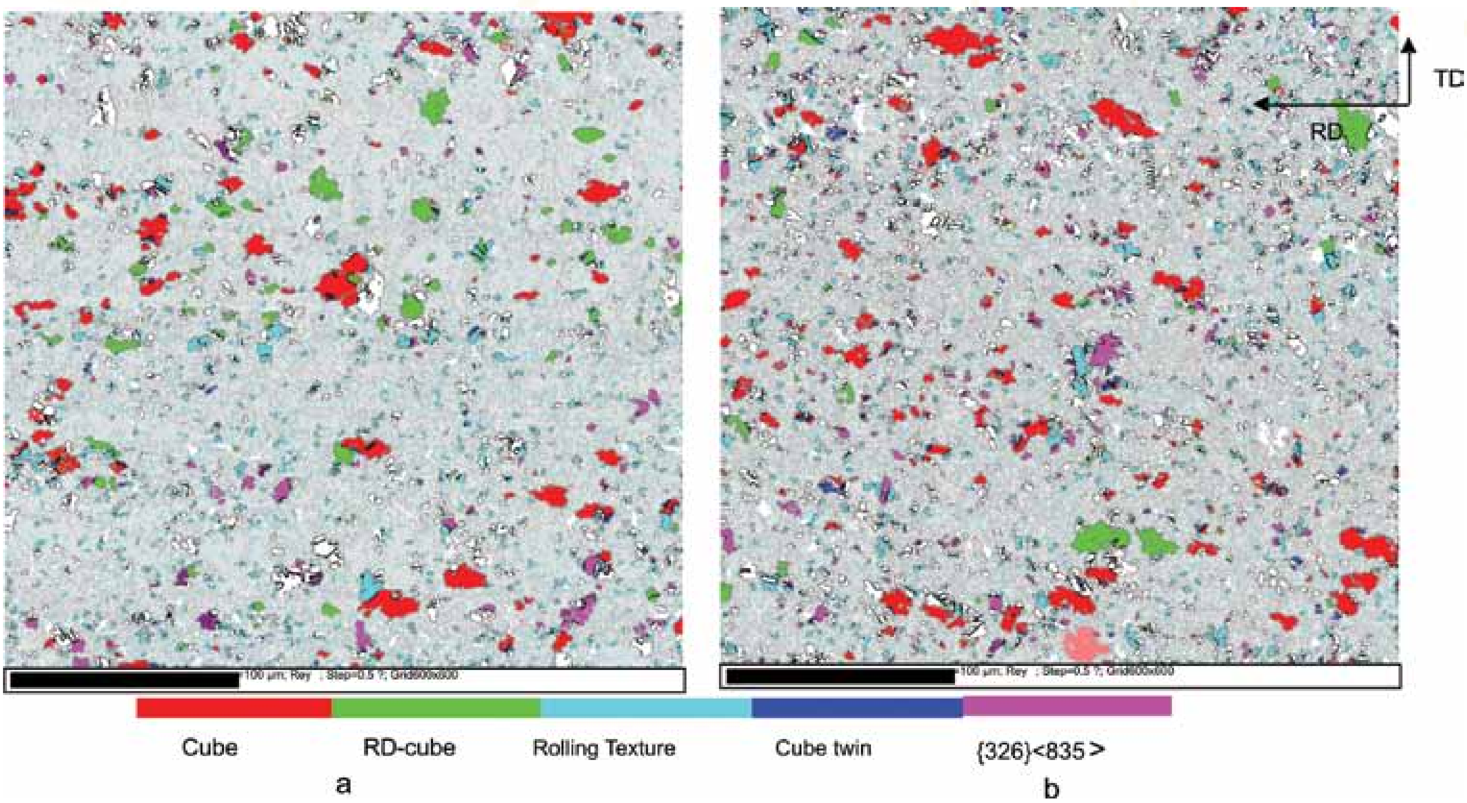


Transmission electron microscopy image showing the initiation of localized shear banding .

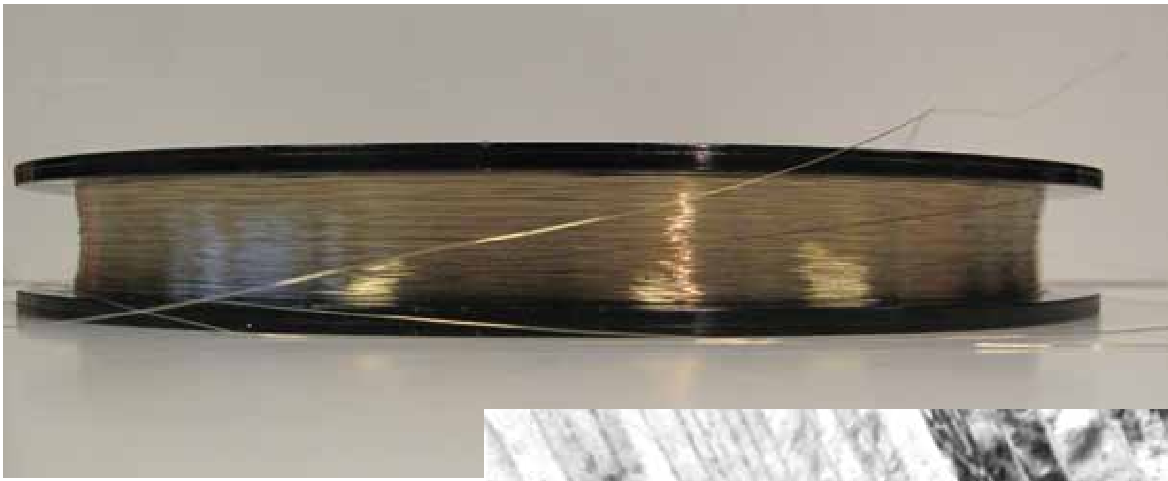
Cube textured substrates for superconducting tapes

Power applications based on second-generation high-temperature superconducting tapes require a metal substrate characterized by a high degree of cube texture. Furthermore, the tapes must ideally be non-magnetic and retain enough strength against tension during processing in a reel-to-reel production line. Commercial tapes still have a Curie temperature larger than that required for applications and their strength is hardly good enough. Risø DTU and Beijing University of Technology succeeded in developing Ni0.91W0.09 and Ni88V0.12 alloys with improved properties while retaining a satisfactory cube texture. These developments have been possible thanks to detailed investigations of the development of microstructure during deformation and recrystallization which were the basis for the optimization of an intermediate recovery rolling process and a multi-step annealing technique.

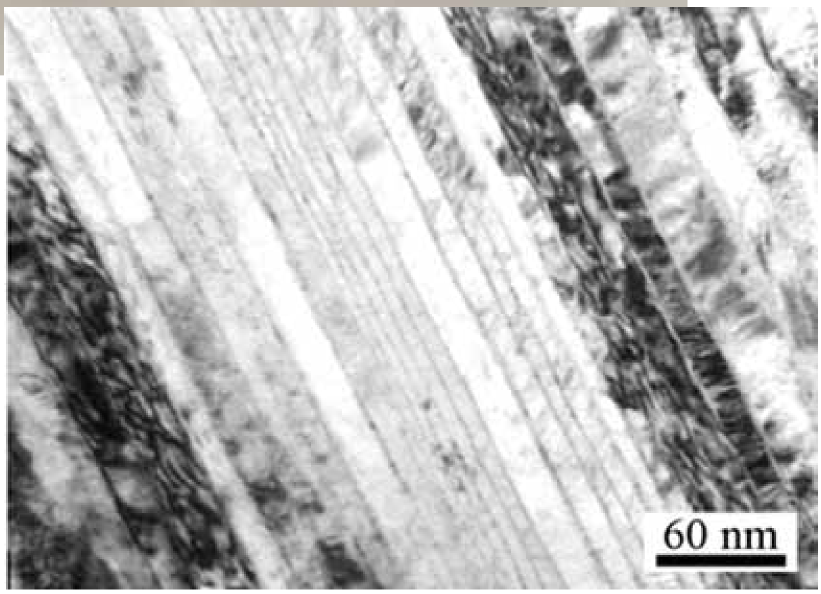
Micrographs illustrating the influence of an intermediate annealing process on the development of cube texture in Ni9W tapes. Two-step annealing (left), three-step annealing (right).



Steel wires with extreme strength



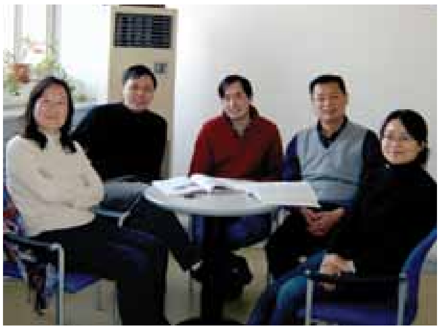
Final cold-drawn wires.



Microstructure of wire showing the lamellar structure.

The strength of a metal can be increased many times by cold deformation and for steel it can be raised more than 10 times and reach 5.000 MPa in a steel wire – the strongest metallic material in the world. Today these wires have wide applications as suspension cables for bridges and reinforcement of car tires and tomorrow they may give strength to large blades in wind turbine generators. The high strength has its cause in the nanometer scale lamellar structure within the wire. The fundamental strengthening mechanisms are strain hardening, grain boundary hardening and solid solution strengthening. In collaboration between Risø DTU, Tsinghua University and Chongqing University these contributions have been identified by means of high resolution electron microscopy, and they have been found to be linearly additive. Correlations between structural parameters and strength have led to a better understanding of the mechanisms giving extreme strength. The findings give general guidelines for the development of new and advanced high-strength metals and alloys.

Exchange



IMR SYNL, December 2010: Dr. Lei Lu (IMR SYNL), Dr. Hongwang Zhang (IMR SYNL), post doc Yubin Zhang (Risø DTU), Dr. Nairong Tao (IMR SYNL), PhD student Fengxiang Lin (Risø DTU).

Visits from China to Risø DTU, Denmark

Prof. Andy Godfrey, Tsinghua
Dr. Lei Lu, IMR SYNL (1 month)
Dr. Hongwang Zhang, IMR SYNL (2 months)
PhD student Zhaoping Luo, IMR SYNL (1 month)
PhD Yonghao Zhang, Chongqing (3 months)

Visits from Risø DTU to Tsinghua University

Dr. Techn. Niels Hansen
Senior Scientist Xiaoxu Huang
Dr. Techn. Dorte Juul Jensen
Dr. Techn. Grethe Winther

Visits from Risø DTU to IMR SYNL:

Senior Scientist Xiaoxu Huang
PhD student Fengxiang Lin
Postdoc Yubin Zhang

Visits from Risø DTU to Chongqing University

Dr. Techn. Niels Hansen
Senior Scientist Xiaoxu Huang
Dr. Techn. Dorte Juul Jensen

Public Outreach

Dr. Techn. Grethe Winther from Risø DTU gave a lecture on metals in Danish national television, DR2, in which she explained how processing can manipulate the grain structure and the formation of defects in the otherwise perfect crystal lattice and how this gives the metal its great strength and formability.

Publications

Journal articles

1. Chen, X. P.; Li, M. Y.; Liu, Q. ; Han, Z., Effect of secondary phases evolution in the first sintering process on the critical current density of Bi-2223/Ag tapes, Physica C, 469 (2009) p. 116.

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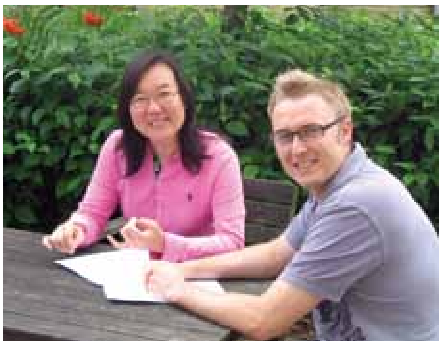
15. Qian, Y.; Zhi-Wei, S.; Ju, L.; Huang, X.; Lin, X.; Jun, S.; Evan, M., Strong crystal size effect on deformation twinning. Nature, 463 (2010) p. 335-338.



Dr. Lei Lu (IMR SYNL) and PhD student Jacob Kidmose (Risø DTU).

16. Qin, E. W.; Lu, L.; Tao, N. R.; Lu, K., Enhanced fracture toughness of bulk nanocrystalline Cu with embedded nano-scale twins, Scripta Materialia, 60 (2009) p. 539-542.

17. Qin, E. W.; Lu, L.; Tao, N. R.; Tan, J.; Lu, K., Enhanced fracture toughness and strength in bulk nanocrystalline Cu with nanoscale twin bundles, Acta Materialia, 57 (2009) p. 6215-6225.

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Risø DTU, July 2010: Prof. Andy Godfrey, Tsinghua, Dr. Hongwang Zhang (IMR SYNL), Dr. Techn. Grethe Winther (Risø DTU), Senior Scientist Oleg Mishin (Risø DTU).

Conference proceedings

1. Azuma, M.; Goutianos, S.; Hansen, N.; Winther, G.; Huang, X., In-situ observation of void formation in dual phase steel, Proc. of 31st International Risø Symposium on Materials Science (2010) p. 243-250.

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Other

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Honors and Awards

Dr. Techn. Dorte Juul Jensen was invited to join the Royal Danish Academy of Sciences and Letters which is an old, venerable club of outstanding scientists, engaged on basic scientific research. The Academy has about 250 Danish and 250 international members.

Prof. Ke Lu was awarded the title MRS Fellow for the discovery of nanotwinned metals and development of nanostructured metals through the advancement of synthesis technologies, thereby revealing novel properties and performance.

Prof. Ke Lu gave the 12th Kelly Lecture at the University of Cambrigde.

Staff

Materials Research Division, Risø DTU

Risø DTU

Scientists:
Dorte Juul Jensen (Principal investigator)
Grethe Winther (Danish coordinator)
Jean-Claude Grivel
Niels Hansen
Xiaoxu Huang
Oleg Mishin
Wolfgang Pantleon

Post docs:
Xiaodan Zhang
Yubin Zhang
Yue Zhao

PhD students:
Lin Fengxiang
Jacob Kidmose

Technicians:
Gitte Christiansen
Lars Lorentzen
Preben Olesen

Administration:
Kamilla Fugleberg

Long term guests:
Mangmang Gao (Beijing University of Technology)
Yukui Gao (Beijing Institute of Aeronautical Materials)

IMR SYNL landmark

IMR SYNL

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Ke Lu (Principal investigator)
Hongwang Zhang (Chinese coordinator)
Lei Lu
Shihong Zhang

PhD students:
Zhaoping Luo

Technicians:
Xiao Si

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Tsinghua University

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Jing Zhu
Wei Liu

PhD students:
Guomin Le
Long Liu
Haiyan Xu
Yue Yuan

The Bell Pagoda, Chongqing University

Chongqing University

Scientists:
Qing Liu
Tianlin Huang
Zhiqing Zhang

PhD students:
Yong Hao Zhang
Liping Deng

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